Temporal Trends in Pelagic Communities and Forage Fish Removals:

Connections Between Zooplankton, Atlantic Herring (*Clupea harengus*), and Herring Consumption Across the Northeast U.S. Continental Shelf

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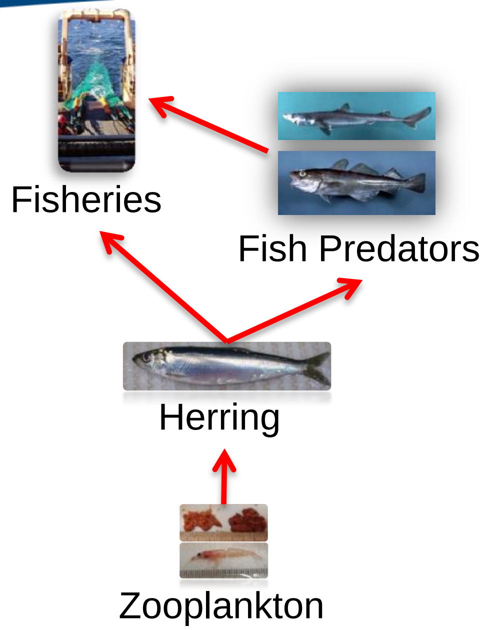
Plankton Fisheries

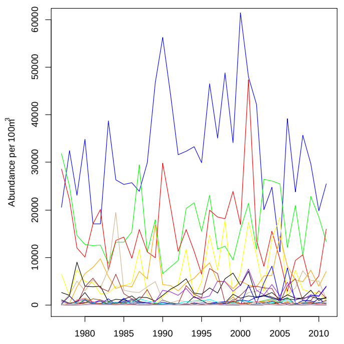
Major Objectives

- Examine trends of 4 major pelagic communities of the northeast U.S. continental shelf, and explore link between plankton and commercial fisheries:
  - zooplankton and Atlantic herring abundance
  - herring removals from fish consumption and commercial landings.
- Relate annual amounts of shelf-wide herring consumption to trends in the pelagic environment.



Rationale

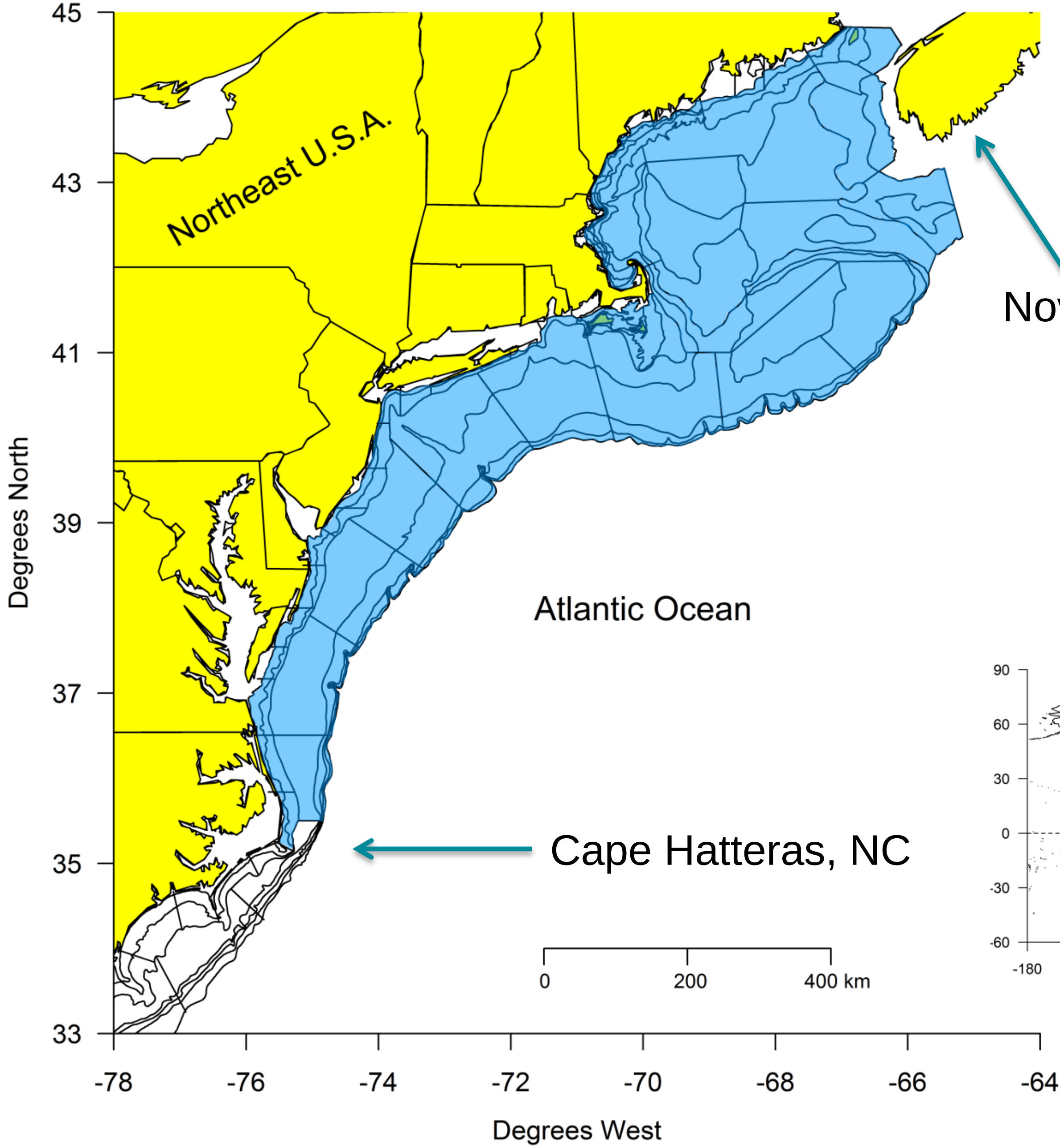
- Global concern for forage fishes (e.g. Atlantic herring) as they are directly targeted by fisheries, but are also food for targeted fishes and other predators of interest.
- Hold a keystone role as predator and prey linking lower and upper trophic levels.
- Imperative to provide best available herring assessment science given their potential disruption due to global change.

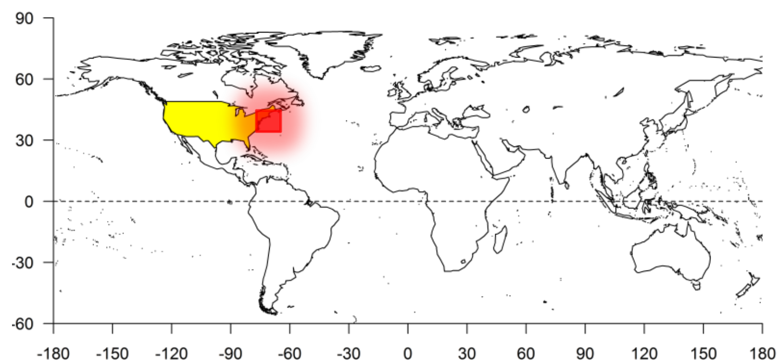


Available Data

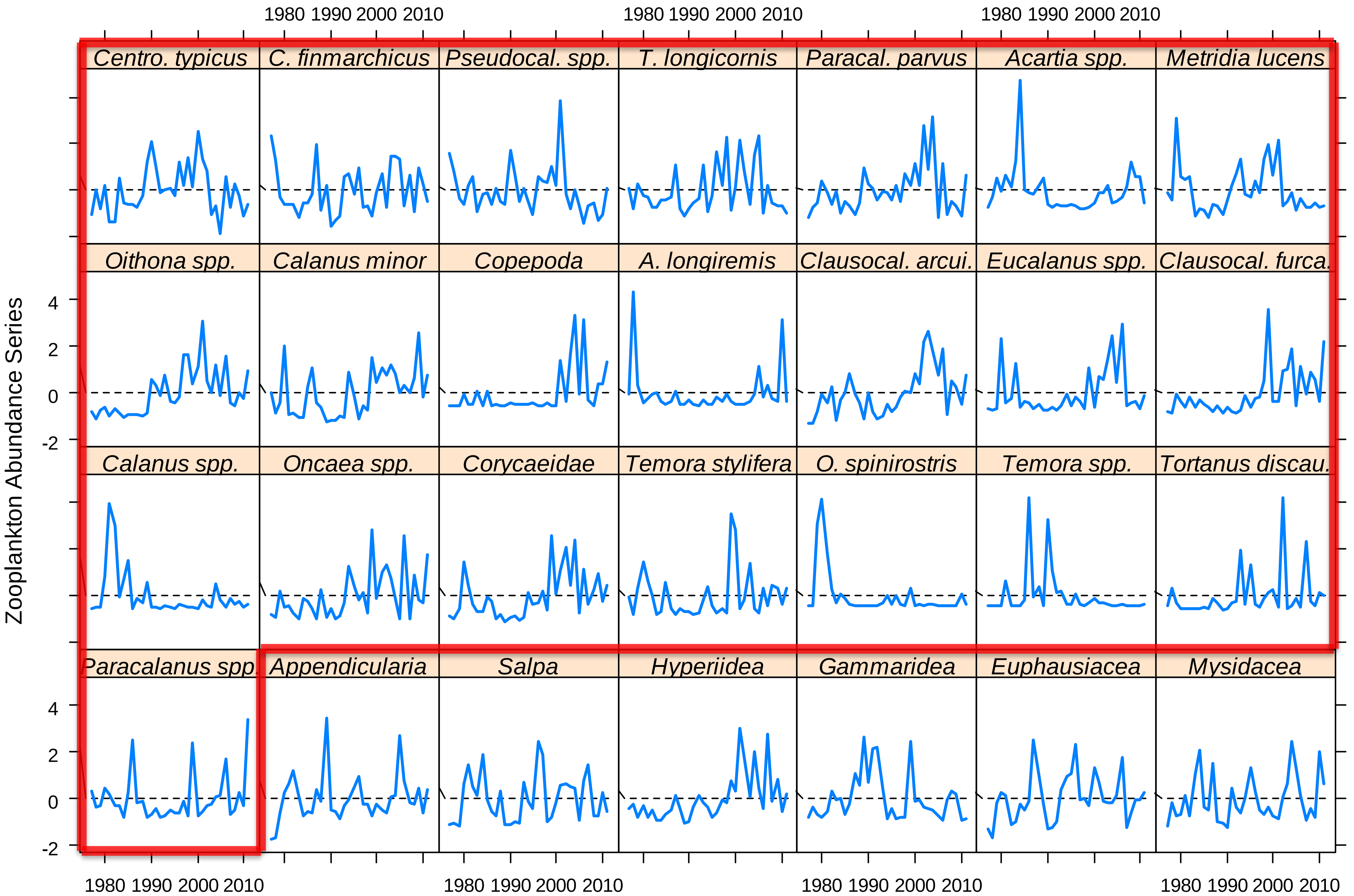
1. Zooplankton abundance: 28 time series from seasonal surveys, 1977-2011.
2. Herring abundance: 2 time series from seasonal bottom trawl surveys, 1977-2011.
3. Fish diets: 13 time series for major herring predators from seasonal bottom trawl surveys, 1977-2011.
4. Herring landings: 1 time series, 1977-2011.

Northeast U.S. Continental Shelf





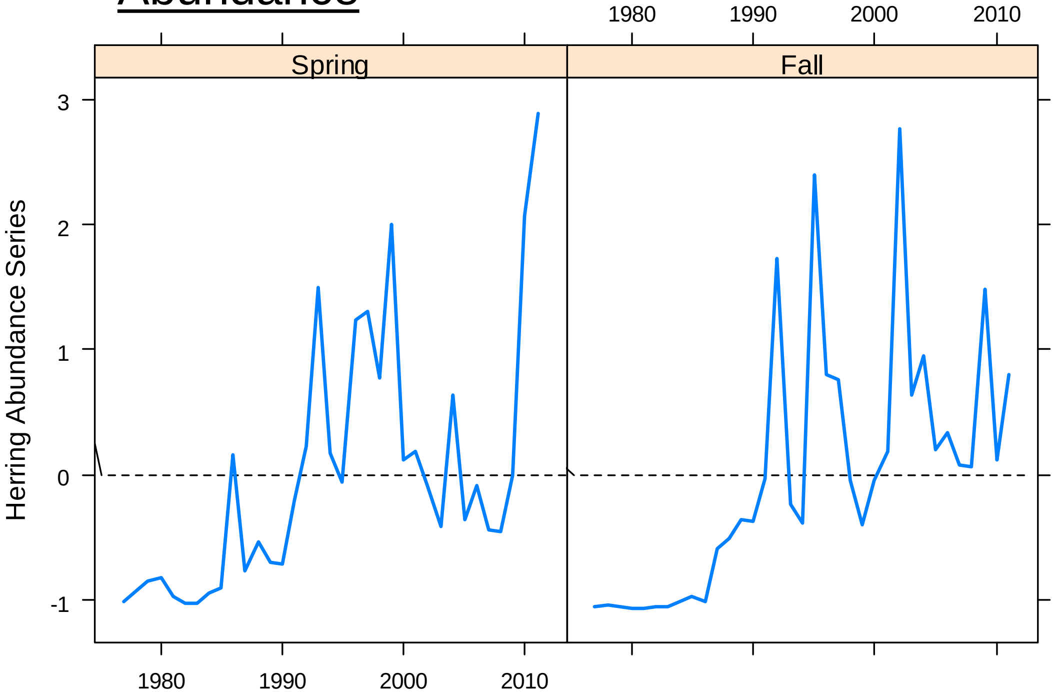
Zooplankton Abundance



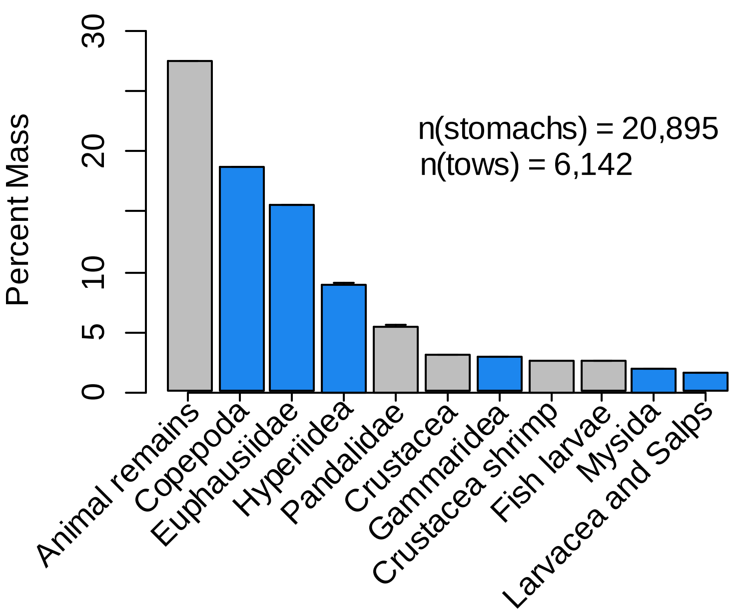
Herring Abundance and Diet

- Annual stratified mean number of herring per tow.
- Herring collected during seasonal bottom trawl surveys.
- Time series means ~ 25-30 fish per tow.

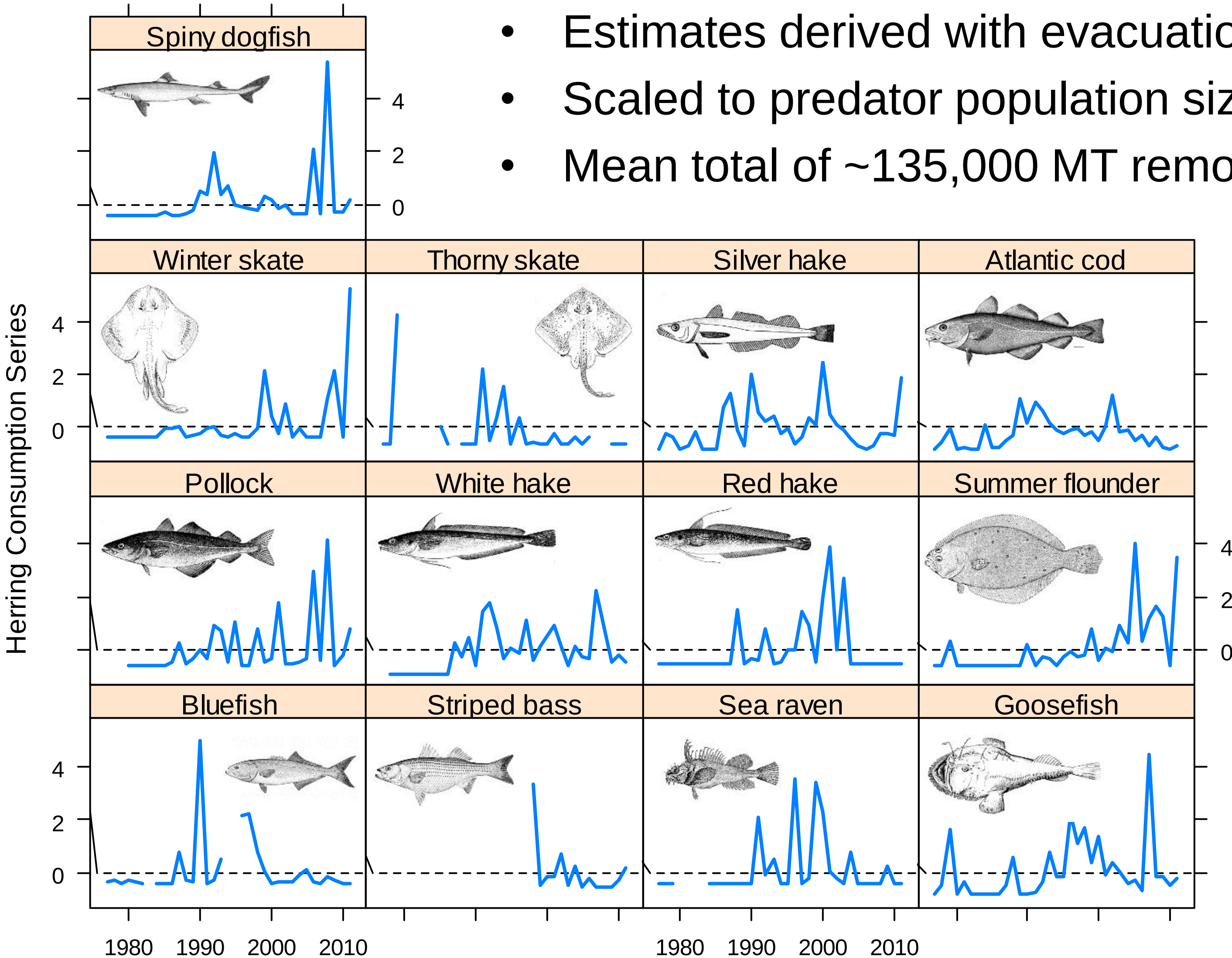
Abundance



Diet



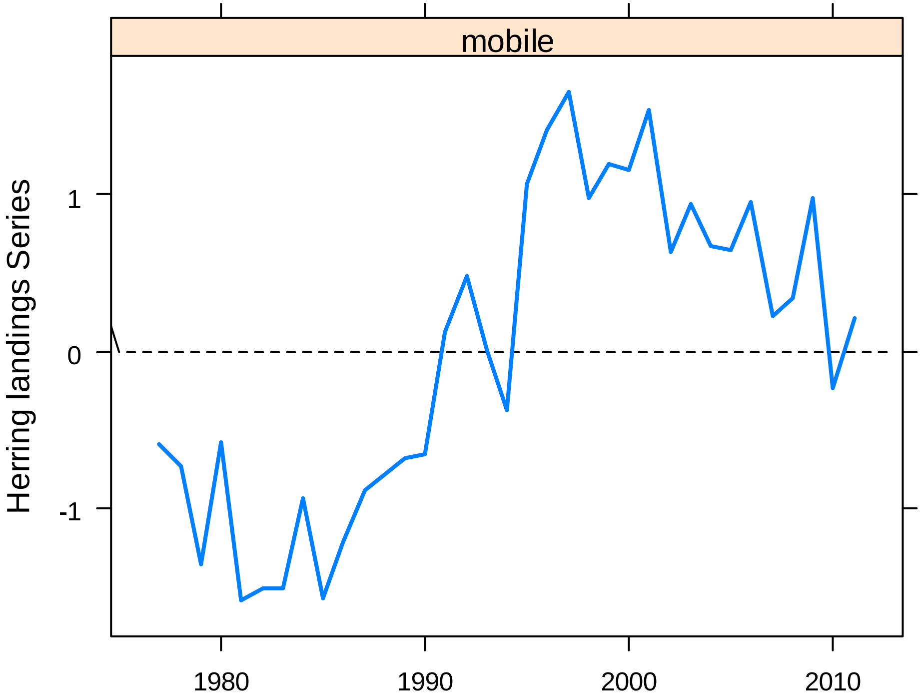
Herring Consumption



- Estimates derived with evacuation rate models.
- Scaled to predator population size.
- Mean total of ~135,000 MT removed annually.

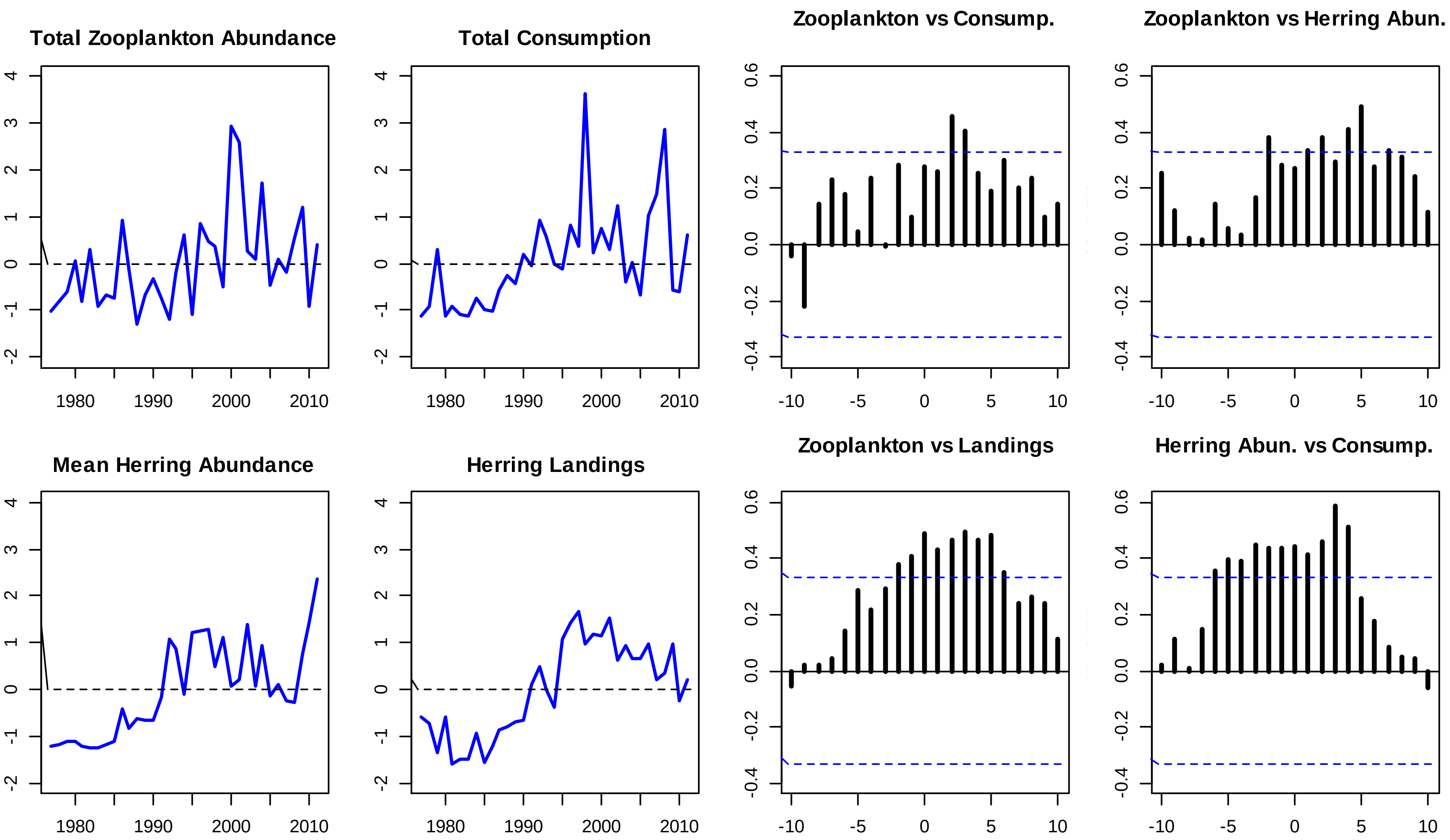
Herring Landings

- Annual U.S. herring catches using mobile gear.
- Numbers generated from 2012 herring assessment.
- Standardized time series.



- Time series means ~ 75,000 MT fish per year.

Positive Time Series Correlations



NOAA FISHERIES

Time Series Modeling

- Multivariate autoregressive state-space models

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \\ y_8 \\ y_9 \\ y_{10} \\ y_{11} \\ y_{12} \\ y_{13} \end{bmatrix}_t = \boxed{\begin{bmatrix} Z_{1,1} & Z_{1,2} & Z_{1,3} & Z_{1,4} & Z_{1,5} \\ Z_{2,1} & Z_{2,2} & Z_{2,3} & Z_{2,4} & Z_{2,5} \\ Z_{3,1} & Z_{3,2} & Z_{3,3} & Z_{3,4} & Z_{3,5} \\ Z_{4,1} & Z_{4,2} & Z_{4,3} & Z_{4,4} & Z_{4,5} \\ Z_{5,1} & Z_{5,2} & Z_{5,3} & Z_{5,4} & Z_{5,5} \\ Z_{6,1} & Z_{6,2} & Z_{6,3} & Z_{6,4} & Z_{6,5} \\ Z_{7,1} & Z_{7,2} & Z_{7,3} & Z_{7,4} & Z_{7,5} \\ Z_{8,1} & Z_{8,2} & Z_{8,3} & Z_{8,4} & Z_{8,5} \\ Z_{9,1} & Z_{9,2} & Z_{9,3} & Z_{9,4} & Z_{9,5} \\ Z_{10,1} & Z_{10,2} & Z_{10,3} & Z_{10,4} & Z_{10,5} \\ Z_{11,1} & Z_{11,2} & Z_{11,3} & Z_{11,4} & Z_{11,5} \\ Z_{12,1} & Z_{12,2} & Z_{12,3} & Z_{12,4} & Z_{12,5} \\ Z_{13,1} & Z_{13,2} & Z_{13,3} & Z_{13,4} & Z_{13,5} \end{bmatrix}} \boxed{\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix}} + \boxed{\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \\ a_7 \\ a_8 \\ a_9 \\ a_{10} \\ a_{11} \\ a_{12} \\ a_{13} \end{bmatrix}} + \boxed{\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \\ v_7 \\ v_8 \\ v_9 \\ v_{10} \\ v_{11} \\ v_{12} \\ v_{13} \end{bmatrix}}$$

$$\boxed{\begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_{13} \end{bmatrix} \sim \mathrm{MVN}\left(\begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}, \begin{bmatrix} \mathrm{R}_{1,1} & \mathrm{R}_{1,2} & \dots & \mathrm{R}_{1,13} \\ \mathrm{R}_{2,1} & \mathrm{R}_{2,2} & \cdots & \mathrm{R}_{2,13} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{R}_{13,1} & \mathrm{R}_{13,2} & \dots & \mathrm{R}_{13,13} \end{bmatrix} \right)}$$

- Non-stationary data
- Missing data
- Dynamic factor analysis
- Model process and observation error separately
- EM algorithm
- Trend based on random walk

Identifying Trends

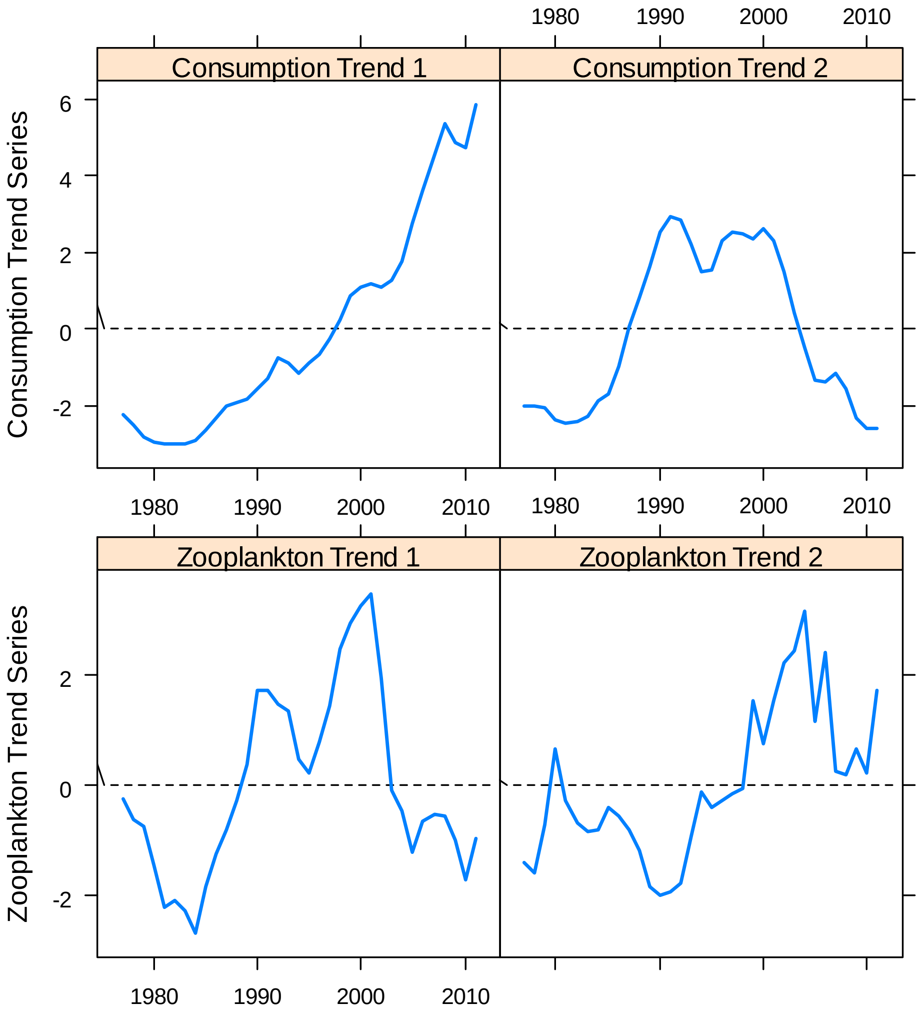
Model Selection

R = covariance matrix structure;
m = number of trends;
AICc = selection measure.

R	m	AICc
diagonal and equal	**2**	**1156.9**
diagonal and equal	1	1164.1
diagonal and equal	3	1176.1
diagonal and unequal	2	1179.7
diagonal and unequal	1	1187.2
diagonal and unequal	3	1199.0
unconstrained	1	1244.7
unconstrained	2	1268.8
unconstrained	3	1298.9
other combinations	>3	≥1197.4

R	m	AICc
diagonal and equal	**2**	**2644.9**
diagonal and equal	3	2646.1
diagonal and unequal	3	2647.6
diagonal and unequal	2	2656.2
diagonal and equal	1	2664.1
diagonal and unequal	1	2674.3
unconstrained	1	3292.0
unconstrained	2	3412.3
unconstrained	3	3580.6
other combinations	>3	≥2650.5

Trends

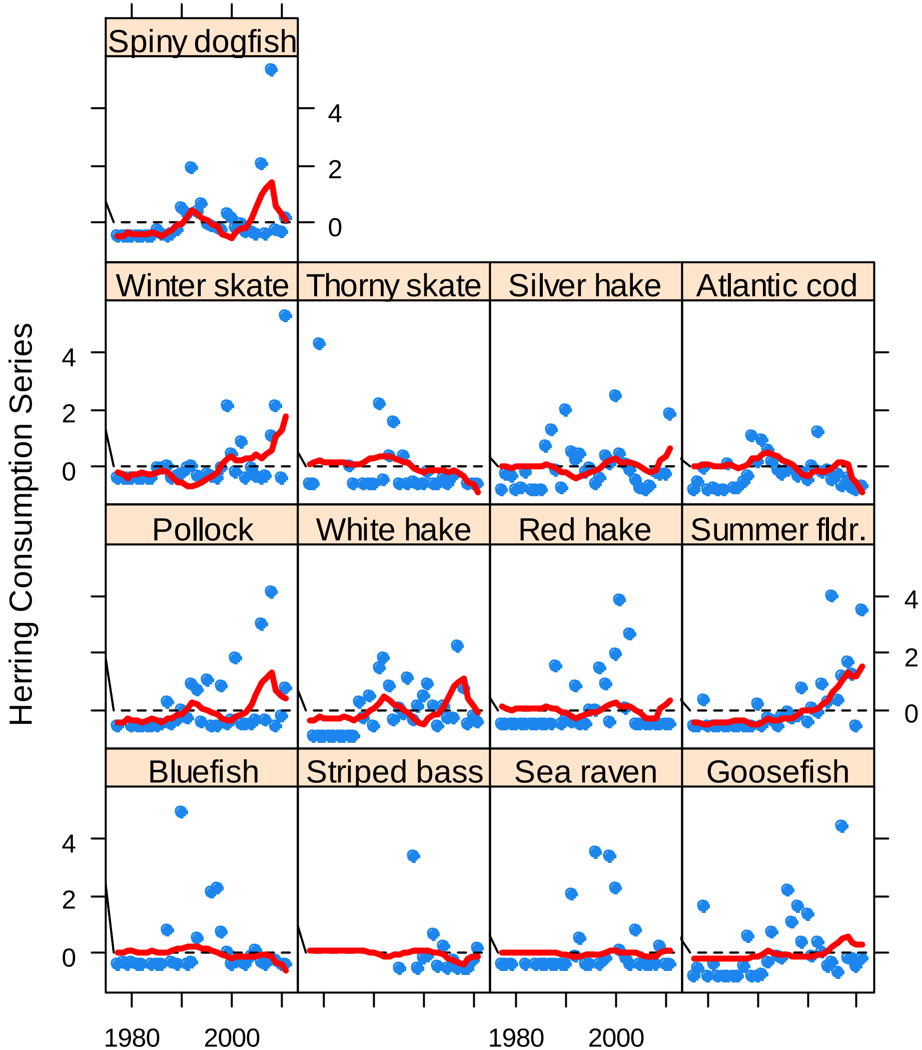


Modeling Herring Consumption

Model Selection

R = covariance matrix structure; m = number of trends; AICc = selection measure.

R	m	Explanatory variables	AICc
diag. equal	2	-	1156.9
diagonal and equal	**2**	**zooplankton trend 1**	**1150.9**
diagonal and equal	2	zooplankton trend 2	1173.2
diagonal and equal	2	zooplankton trends 1&2	1167.6
diagonal and equal	2	spring herring abun.	1179.9
diagonal and equal	2	fall herring abun.	1185.0
diagonal and equal	2	spring&fall herring abun.	1202.4
diagonal and equal	2	herring landings	1185.7
diagonal and equal	2	other combinations	≥ 1176.2



Conclusions

- Food web surrounding Atlantic herring is tightly coupled, particularly the influence of zooplankton community on herring predation.
- Common trends identified in herring consumption, and model improved with addition of zooplankton abundance.


Plankton


Fisheries

Discussion

- Managing fisheries resources remains an intriguing challenge with pivotal roles of stocks as major prey for commercial fishes and fisheries.
- Competition between ecological and fisheries interests yields trade-offs.
- Advancing the use of oceanographic and ecological processes into assessments is essential with their potential disruption due to global change.

Acknowledgements

- 2012 Herring Assessment Working Group.
- Numerous survey crew and scientists throughout years of sampling.
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